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Studies on Drought stress in Vegetables

K. Nirosha[1], B. Naveen Kumar[2] and B. Nithya Sri[3]

[1]Assistant Professor, Dept. of Vegetable Science, SKLTHU, Hyderabad
[2]Assistant Professor and Vice-principal, Horticulture Polytechnic, Ramagirikgilla
[3]M.Sc. (Hort.), Department of Vegetable Science, SKLTHU, Hyderabad

SUMMARY

Different studies of drought stress tolerance in vegetables has yielded crucial insights into the intricate mechanisms governing a plant's ability to endure water scarcity. Structural attributes like cuticle thickness, stomatal density, and root architecture play pivotal roles in managing water regulation, directly influencing a plant's resilience to drought. Key gene pathways controlling stress perception, signal transduction, and activation of stress-responsive genes have been unveiled, with transcription factors like DREB and bZIP emerging as pivotal drivers of adaptive plant reactions. The interplay between exogenous hormones and plants under drought stress reveals a complex dynamic that can either enhance or hinder a plant's drought-coping mechanisms. Notably, the significance of ABA is evident as it aids stomatal closure, reduces transpiration, and initiates molecular cascades that enhance stress tolerance.

INTRODUCTION

Vegetables are essential in human diets, offering antioxidants, vitamins, and dietary fibers, complemented by unique flavors, textures, and cultural value. Most vegetables contain more than 90% water, so drought stress is a significant impediment, constraining growth, development and yield. In many years, vegetables have evolved multifaceted defence mechanisms to cope with drought stress and maintain growth and metabolism. However, vegetable responses to drought stress vary greatly based on species, stress severity, growth stage, and vegetable parts. Moreover, each vegetable has its own critical stages of water requirement; if water is scarce during these periods, it can lead to a significant reduction in yield and quality. Likewise, natural acclimatization also helps vegetables endure diverse environmental constraints. These strategies might fall short of mitigating the rapid impact of drought stress. Under drought stress, vegetables can produce reversible and irreversible physiological and biochemical changes. Therefore, the improvement of vegetable drought tolerance is also multifaceted, and innovative cultivation methods and exogenous regulatory technology are required to meet the normal growth and development needs of global vegetables. Drought lead to a significant decline in vegetable quantity and quality which ultimately affects food security. Most vegetables suffer sensitivity to drought at around the threshold of ~20% water content. A water deficiency triggers osmotic, ionic, and oxidative stress, closing stomata for a short time and eventually causing vegetables to shrink. This limits CO2 uptake, impairs carboxylation, increases photorespiration, and enhances oxidative damage to organelles due to the increased reactive oxygen species (ROS) under drought stress.

The critical stages of water requirement and effect of drought for different vegetables

S.No.	Vegetable Crop	Critical Stage of Water Requirement	Effect of Drought
1.	Leafy vegetables	During the process of plant growth and development.	Leaf toughness, inadequate foliage development, and nitrate accumulation.
2.	Potato	The process of tuber formation and the growth of tubers.	Inadequate tuber development and low yield, along with tuber splitting.
3.	Pea	The process of flower formation and the filling of pods.	Decreased root nodulation and stunted plant growth, along with inadequate grain filling.
4.	Lettuce	Consistently throughout the entire developmental process.	Leaf toughness, inadequate growth of plants, and tip burn.
5.	Melons	The process of flowering and uniform fruit development throughout.	Muskmelons exhibit diminished fruit quality due to reduced total soluble solids (TSS), decreased sugar and ascorbic acid levels, and increased nitrate content in watermelon fruits.

6.	Okra	Flowering and pod development.	Intensive decrease in the yield, fiber development, and potential infestation by mites.
7.	Onion	Bulb enlargement and bulb formation.	Splitting and doubling of the bulb decrease the shelf life.
8.	Cucumber	Across the flowering period and development of fruits.	Deformed and less vigorous pollens, bitterness in taste, and abnormal fruit shape and size.
9.	Turnip, carrot, and radish	Development of roots.	Poor and distorted growth of roots, the production of harmful nitrates, and ultimately pungent odour of carrots.
10.	Cabbage and cauliflower	Formation and enlargement of the head.	Tip burning of stiff leaves; browning and buttoning in cauliflower curd.
11.	Eggplant	Flower development and fruit setting.	Poor development of fruit color with reduced yield.
12.	Chili and Capsicum	Development of fruits and fruit setting.	Shedding of juvenile flowers and fruits and reduced dry matter production and nutrient uptake.
13.	Tomato	Period of flowering and fruits rapid enlargement.	Flower shedding hindered fertilization and decreased the size of fruits and splitting disorders were attributed to calcium deficiency.

Vegetable species under drought stress: physiological and ROS metabolite aspects.

S. No.	Vegetable Crops and Cultivation Condition	Drought Stress Treatmen	Impact on Crop and Drought Stress Toleranc
1.	Potato (*Solanum tuberosum* L. cultivars) in greenhouse	Irrigation interruption for 12–13 days before tuber formation.	Decrease in: relative water content (RWC); leaf osmotic potential. Elevation of: nitrogen (N) levels and augmented levels of proteins; proline within the leaves.
2.	Lettuce (*Lactuca sativa* L.) Veneranda cultivar in greenhouse	Watering at 90% and 80% field capacity, followed by a 4-day irrigation pause before harvest (inducing acute stress).	Increase in: carotenoids; biomass; chlorophyll content; flavonoids; phenolic acids.
3.	Lettuce (*Lactuca sativa* L.) butterhead (Aquino) and red butterhead (Barlach) cultivar in greenhouse	Soil water contents of 70% and 40%	Reduction in PSII efficiency; elevated biomass.
4.	Eggplant (*Solanum melongena* L.) field	Seven regimes of irrigation.	Reduction in: fruit weight and firmness; total sugars; proteins. Increase in: CAT and APX activity; total phenols; flavonoids.
5.	Amaranth (*Amaranth tricolor; Amaranth cruentus*) in greenhouse	Suspension of watering for 14 days.	Reduction in: plant height, leaves, roots, stem fresh and dry weight; leaf area; chlorophyll content. Increase in transpiration efficiency.
6.	Wild asparagus (*Asparagus acutifolius* L.) in greenhouse	Leaf water potential of −1.4 MPa and −2.4 MPa over 6 days.	Decrease in net photosynthesis.
7.	Common chicory (*Cichorium intybus* L.) in greenhouse	80%, 60%, and 40% of field capacity.	Increase in: SOD and CAT activity; proline and ascorbic acid content; abscisic content in leaves.
8.	Cassava (*Manihot*	50% and 20% of field	Reduction in: chlorophyll content and RWC

	esculenta Crantz), cv. SC205, GR4, RS0I, and SC124 in glasshouse	capacity.	and plant height. Increase in: H2O2; malondialdehyde (MDA), ascorbic acid; glutathione; SOD and CAT activity; total phenols. Overexpression of Mn-SOD, CAT, and GR genes.
9.	Cabbage (*Brassica oleracea var. capitata*) in greenhouse	80% and 60% of the field capacity.	Increase in: H2O2, lipid peroxidation, electrolyte leakage, proline content, and sucrose. Reduction in: biometric parameters (plant height, stem diameter, number of leaves, leaf area, fresh and dry shoot weights); photosynthesis; stomatal conductance and transpiration and chlorophyll content.
10.	Tomato (*Solanum lycopersicum* L., cv. landrace Cietttaicale and Moneymaker) in growth chamber	Treatment irrigation with 50% of the field capacity every 48 days for twenty days.	Reduction in: osmotic potential, stomatal conductance, photochemical efficiency of PSII, leaf starch. Increase in: non-photochemical fluorescence quenching; ABA and IAA contents in leaves and roots; soluble sugars; lipid peroxidation; proline and antioxidant activity in roots.
11.	Pepper (*Capsicum annum* cultivars (Nongchengjiao-2 and Shansshu-2001)) in greenhouse	Grown under four water regimes: 80, 60, 40, and 20 of field capacity for 6, 12, 18, and 24 days.	Reduction in RWC; increased proline content, total soluble proteins, and SOD, POD, and CAT activity at the onset of stress; decreased leaf area and fruit yield.
12.	Sage (*Salvia officinalis*) in field	Stop irrigation for six weeks.	Hampers stomatal closure; reduction in CO2 assimilation; increase in NADPH.
13.	Pepper (*Capsicum chinense*) (cultivars. Rex and Genesis), Capsicum annum cv. Padron)) in Greenhouse.	Restriction of water during the flowering stage for 7, 10, 14, 18, and 21 days.	Noticeable decrease in RWC, along with an increase in electrolyte leakage and proline content.
14.	Soya bean (*Glycine max* L.) in field	Treatments applied to control drought at different reproductive phases.	Drought reduces the seed germination.
15.	Okra (*Abelmoschus esculentus* L. Moench) in field experiment	Exposed to water deficit under various waters regimes for 5 or 10 days.	Waters restrictions exceeding ten days during the reproductive period result in diverse growth and yield effects.

CONCLUSION

This comprehensive knowledge can be harnessed by researchers and agricultural experts to devise innovative strategies for bolstering drought stress tolerance in vegetable crops. Approaches may span from traditional breeding to biotechnological interventions, including genetic manipulation and targeted hormone treatments. By optimizing structural traits, activating stress-responsive genes, and modulating hormone interactions, agricultural productivity and sustainability can be advanced in water-scarce regions. The continual pursuit of research in this field promises further breakthroughs, propelling the development of robust crop varieties and cultivating a more sustainable agricultural future.

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